

# NASA/University JOint VEnture (JOVE)Program

## FINAL TECHNICAL REPORT

- I. **Summary of research and related education and outreach efforts conducted under this NASA/JOVE grant. (Attach additional page(s) and/or relevant documentation as necessary.)**

This project dealt with design, analysis, and testing of new types of planar and integrated antennas operating in the microwave frequency range. The following was accomplished during this project period:

- (1) **Research Results**: the following planar antennas were designed, analyzed, and tested:

- (a) **A uniplanar, coplanar waveguide / slotline balanced mixer integrated with a slot antenna**: The mixer utilizes even and odd modes on a coplanar waveguide to create a singly balanced mixer. The RF signal is fed quasi-optically as an even mode on the coplanar waveguide through a slot antenna while the local oscillator signal is fed to the waveguide as an odd mode through and even mode to odd mode converter. The two signals mix in two Schottky diodes to produce the IF signal. The resulting mixer circuit is simple, compact, and efficient. Analysis was carried out using the Finite-Difference Time-Domain (FDTD) method.
- (b) **A double-balanced mixer integrated with twin-slot antenna**: The circuit in part (a) was successfully modified to produce a doubly balanced mixer using four Schottky diodes and twin slot antennas. A low conversion loss was obtained.
- (c) **A broadband two-layer microstrip antenna fed using a rectangular ring - type slot**: The antenna consists of two stacked substrates, the bottom substrate has a rectangular conductor patch on one side and a rectangular loop slot in a ground plane on the other side. The top substrate has a rectangular patch on one side only. The loop slot is used for feeding the antenna using a coaxial cable or a

# NASA/University JOint VEnture (JOVE)Program

## FINAL TECHNICAL REPORT

coplanar waveguide. Different combinations of dielectric constants for the two substrates were investigated. Analysis and simulation were carried out using the FDTD method. Measurements were performed using a microwave network analyzer and a near-field antenna measurement system. A broad bandwidth was obtained; the best bandwidth was achieved using a combination of high/low dielectric constants. The antennas produced low cross polarization and low back radiation. The designs are amenable for integration with active devices to produce active microstrip antennas.

- (d) A meander loop microstrip antenna: A gap-coupled meander loop single-layer microstrip antenna suitable for the low microwave frequency range was investigated. This antenna occupies smaller area than conventional microstrip patches for the same operating frequency. The loop produces linear polarization and narrow bandwidth. Circular polarization was obtained by adding a small perturbation to the loop. Bandwidth can be improved using multilayer configurations. Analysis and simulation were carried out using the FDTD method and measurements were performed using a near-field antenna measurement system.

- (2) **Educational Results**: educational achievements during the project period include major capstone design projects for senior students, , creation of new laboratories, and course development / improvement. The following summarizes these accomplishments:

(a) Senior Design Projects:

- (i) Judy Salvati, "Plane-Polar near field antenna measurements," December 1997.
- (ii) Jonathan Frederick, "Uniplanar Microwave mixer integrated with a slot antenna," December 1997.
- (iii) K. Velasquez, "A New Broadband Stacked Patch Microstrip Antenna", May 2000.

# **NASA/University JOint VEnture (JOVE)Program**

## **FINAL TECHNICAL REPORT**

- (iv) Brian Johnson, "The meander loop microstrip antenna," May 2000.
  - (v) Michael Bestenheider, "Comparative study of several thin film microwave power dividers and hybrid couplers," May 2000.
- (b) Laboratory development: Two modern laboratories were created: Microwaves Laboratory and Antennas Laboratory. The laboratories are equipped with state of the art measurement equipment and design and simulation software. Equipment include two 20-GHz Vector network analyzers, 20-GHz scalar network analyzer, 50-GHz spectrum analyzer, 35-ps time-domain reflectometry / transmission with digitizing oscilloscope for time domain measurements, 3'x3' precise planar near-field measurement system, an educational far-field antenna measurement system, 1-GHz impedance analyzer, RF oscilloscopes, computer-controlled milling machine and SMT soldering station for fabrication of microwave circuits and antenna prototypes, and Windows NT and Unix workstations. Software packages include Libra (for RF/microwave circuit design), HFSS (for frequency-domain full wave analysis of high frequency structure using the finite element method), and XFDTD (implements the finite-difference time-domain method for solving Maxwell's equations in three dimensions). The microwave lab also includes optical instrumentation for microwave photonics applications. The two laboratories are used for instruction of three undergraduate courses, senior design projects, and research.
- (c) Course development / improvement: New graduate courses were developed including Microwave Circuits, Antennas and Wave Propagation, Numerical Methods in Electromagnetics, and Satellite Communications. Major improvements were made to the undergraduate courses Electromagnetics 1, Electromagnetics 2, and Microwave Fundamentals, Microwave Fundamentals Laboratory, and Microwave Circuits Laboratory. Improvements include

# NASA/University JOint VEnture (JOVE)Program

## FINAL TECHNICAL REPORT

reorganization of the electromagnetics sequence, assignments of design projects, and creation of new lab manuals.

(3) **Publications:** The following papers were published or currently under preparation:

- (i) M. A. Saed, "Source Modeling in the Finite-Difference Time-Domain Method," presented at the IEEE AP-S International Symposium and URSI Radio Science Meeting, Montreal, Canada, July 13-18, 1996. (Digest page 130)
- (ii) M. A. Saed and J. Fredrick, "A New Uniplanar Coplanar Waveguide / Slotline Balanced Mixer," Journal of Electromagnetic Waves and Applications, Vol. 13, pp. 1531-1537, 1999.
- (iii) M. A. Saed and K. Velasquez, "A Broadband Two-Layer Microstrip Antenna Fed by a Rectangular Loop," in preparation, will be submitted to the Journal of Electromagnetic Waves and Applications.
- (iv) M. A. Saed, "The meander Loop Microstrip Antenna," in preparation, will be submitted to the IEEE Transactions on Antennas and Propagation.

# NASA/University JOint VEnture (JOVE)Program

## FINAL TECHNICAL REPORT

II. Please provide a list of all subject inventions/patents as a result of your grant or provide a statement that there were none.

There were no inventions / patents as a result of this grant

Ullsae  
Signature

11/10/2000  
Date

**PROGRAM AND ABSTRACTS**

**for the**

**1997 URSI North American  
Radio Science Meeting**

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the Canadian National Committee for URSI  
and  
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*in collaboration with*

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the Antennas and Propagation Society of IEEE

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TUESDAY

JULY 15

URSI B

Session 47

Salon Marquette

Finite Difference Time Domain

Co-chairs: C. Trueman, Canada and J. LoVetri, Canada

- 13:10 47.1 Improvements in the Simulation of Absorbing Boundaries for the Finite-Difference Time-Domain Method, N. CALVÉ, A.E. ROS, *Laboratoire d'Electronique et Systèmes de Télécommunications, Brest, France*
- 13:30 47.2 FDTD Analysis and Measurements of Shielded Cellphone Antenna, B. YILDIRIM, E.-B. EL-SHARAWY, *Arizona State University, Tempe, AZ, USA*
- 13:50 47.3 Using Time-Domain Complex-Envelope Representations of Band-Pass Limited Signals in the Finite-Difference Solution of the Wave Equation, P.M. GOGGANS, J.D. PURSEL, *University of Mississippi, University, MS, USA*
- 14:10 47.4 Analysis of a Time Domain FEM with Edge Elements of Different Form, G. MANARA<sup>1</sup>, A. MONORCHIO<sup>1</sup>, G. PELOSI<sup>2</sup>, <sup>1</sup>*University of Pisa and* <sup>2</sup>*University of Florence, Italy*
- 14:30 47.5 Derivation and Verification of a Dispersion Optimized Fourth Order FD-TD Method, G. HAUSSMANN, M. PIKET-MAY, *University of Colorado at Boulder, CO, USA*
- 14:50 47.6 Source Modeling in the Finite-Difference Time-Domain Method, M.A. SAED, *State University of New York at New Paltz, NY, USA*
- 15:10 Coffee Break
- 15:30 47.7 A Comparative Study of the FDTD and the FVTD Schemes, R. SIUSHANSIAN<sup>1</sup>, J.-LO VETRI<sup>1</sup>, N.R.S. SIMONS<sup>2</sup>, <sup>1</sup>*University of Western Ontario, London and* <sup>2</sup>*Communications Research Centre, Ottawa, ON, Canada*
- 15:50 47.8 An FDTD Method with Nonuniform Cylindrical Grids for Inhomogeneous Conductive Media, J. HE, Q.H. LIU, *New Mexico State University, Las Cruces, NM, USA*
- 16:10 47.9 Limitations of Precise Simulations of Handheld Mobile Phones with FDTD, O. VOLES, K. POKOVIĆ, M. BURKHARDT, N. KUSTER, *Swiss Federal Institute of Technology (ETH), Zürich, Switzerland*
- 16:30 47.10 Design of Composite Grating Assisted Mode Couplers for Ultrafast Pulses, T. LIANG, R.W. ZIOLKOWSKI, *University of Arizona, Tucson, AZ, USA*

SOURCE MODELING IN THE FINITE-DIFFERENCE  
TIME-DOMAIN METHOD

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The Finite-Difference Time-Domain method (FDTD) is well known and very widely used in various applications such as scattering, microwave circuits, bioelectromagnetic simulations, antennas, subpicosecond photonic devices, and high speed electronic circuits. Among other factors, the accuracy of all these simulations is strongly dependent on accurate modeling of the excitation sources. Usually, in FDTD implementations, the source-free Maxwell's equations are discretized in a leap-frog time-stepping scheme. Then, hard sources are added to the computational domain by forcing some field components at some locations to equal the desired excitation pulse or sinusoid. Pulse sources must be placed far enough from the first discontinuity so that they expire and then removed before seeing the first reflection. This is computationally inefficient since it necessitates a large computational domain. Furthermore, such sources may be impossible to remove before the arrival of the first reflection in many applications such as high speed electronic circuits. Sinusoidal sources cannot be removed and must be turned on for the entire simulation time. This causes spurious reflections since the field components representing the sources are not updated using Maxwell's equations, but instead are forced to equal the desired sinusoidal function all the time.

In this paper, we present source models that solve the above problems associated with commonly used source models. Our FDTD implements the discretized Maxwell's equations for regions with sources. The sources do not need to be removed and all the field components at those locations are updated according to Maxwell's equations. The sources do not cause spurious reflections and can be placed close to the discontinuities saving valuable computation time. The details of the implementation, numerical results, and source models for probe and aperture coupling will be presented at the conference.



## **A NEW UNIPLANAR COPLANAR WAVEGUIDE/ SLOTLINE BALANCED MIXER**

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**Abstract**—This paper presents a new uniplanar microwave mixer circuit. The mixer utilizes even and odd modes on a coplanar waveguide to create a singly balanced mixer. The RF signal is fed quasi-optically as an even mode on a coplanar waveguide through a slot antenna while the local oscillator signal is fed to the same coplanar waveguide as an odd mode through an even-mode to odd-mode converter. The resulting mixer circuit is simple, compact, efficient, and can be scaled easily to millimeter wave frequencies.

### **1. INTRODUCTION**

Uniplanar designs for microwave and millimeter wave circuits are suitable for integration using monolithic techniques. Active components can be easily integrated since the need for via holes and backside metallization are eliminated. Balanced mixer circuits described in the literature usually require 3-dB hybrid couplers such as rat-race or quadrature hybrids [1, 2]. Other designs [3] use traditional planar baluns [4] to realize the proper configuration for a balanced mixer. To reduce the size of the circuit and to extend the frequency range into millimeter and submillimeter waves, quasi-optical techniques have been used [5–7]. In this paper, a new design for a singly balanced mixer circuit is investigated. The mixer utilizes even and odd modes on a coplanar waveguide to create the balanced mixer. The RF signal is fed quasi-optically as an even mode on a coplanar waveguide through a slot antenna while the local oscillator signal is fed to the same coplanar waveguide as an odd mode through an even-mode to odd-mode converter. The need

for a 3-dB hybrid coupler is eliminated resulting in a compact circuit suitable for monolithic fabrication, which can be easily scaled to millimeter wave frequencies. The even-mode to odd-mode converter and the overall mixer circuit with measurement results are presented in section 2 followed by conclusions in section 3.

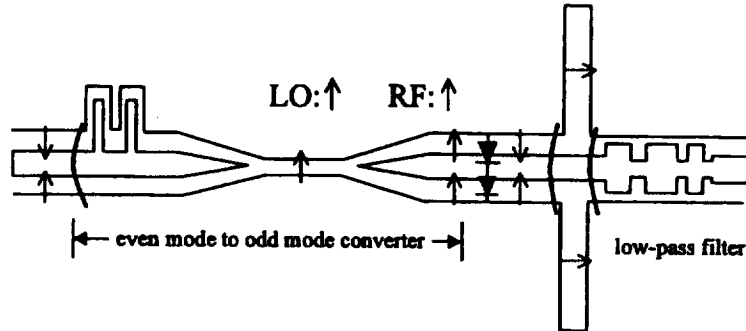


Figure 1. Balanced mixer.

## 2. MIXER CIRCUIT

The proposed mixer is shown in Figure 1. It consists of an even-mode to odd-mode converter using coplanar waveguides and a slotline, two Schottky diodes, a slot antenna, and a stepped-impedance low-pass filter. The local oscillator (LO) signal is fed to this converter so that a slotline mode is produced on a coplanar waveguide. The radio frequency (RF) signal is fed to the same coplanar waveguide quasi-optically through a slot antenna. Two Schottky diodes connected in series are attached to the coplanar waveguide. This arrangement ensures that the diodes are excited properly by the LO and RF signals as required in a balanced mixer, as illustrated in figure 1. The intermediate frequency (IF) signal is extracted using a low-pass filter. Several mechanisms inherent in the design ensure excellent LO to IF isolation. First, the LO signal is reflected back to the diodes by the air bridge at the antenna which shorts out the slotline mode (the LO signal), second, the slot antenna itself will reflect the LO signal back since it cannot radiate the slotline mode at the design frequency (the two sides of the slot will be excited with opposite polarization), and finally the IF low-pass filter will provide even further attenuation. The RF to LO isolation is also excellent since the RF signal received by the

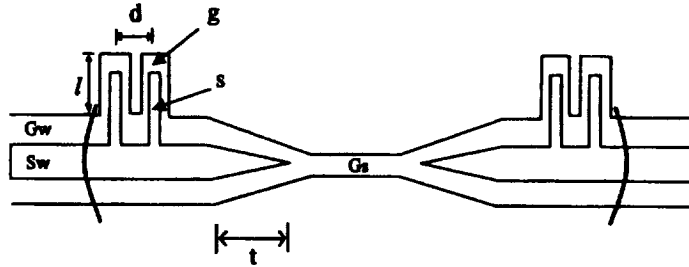


Figure 2. Back to back balun.

slot antenna excites the even-mode in the coplanar waveguide which cannot pass through the slotline to the LO, instead, it will be reflected back to the diodes. RF to IF isolation is ensured by the low-pass filter.

Balun No.	$l$ (mm)	$d$ (mm)	$g$ (mm)	$s$ (mm)	$t$ (mm)
1	2.86	3.3	0.508	1.392	7
2	2.86	2.8	0.508	0.892	7
3	2.26	2.8	0.508	0.892	7

Table 1. Dimension of back to back baluns.

The even-mode to odd-mode converter uses a coplanar waveguide to slotline transition. This transition is a modification to a balun proposed in [8]. In [8], the center conductor of the coplanar waveguide is abruptly truncated. Experimentally, a tapered center conductor yielded a better return loss over a wide bandwidth. The dimensions of the interdigital section of the coplanar waveguide determine the frequency range for which the balun performs well. Several back to back baluns, as shown in Figure 2, were fabricated using a milling machine on an RT/Duroid 6010.8 dielectric substrate which has a dielectric constant of 10.8 and thickness of 0.65 mm. Figures 3 and 4 show the measured return loss and insertion loss, respectively, for three baluns with the dimensions given in Table 1. The input and output coplanar waveguides are designed to have 50 ohm characteristic impedances (gap width  $Gw = 0.508$  mm and strip width  $Sw = 1.785$  mm). The slotline has a gap width  $Gs = 0.28$  mm resulting in 85 ohm characteristic impedance. We selected balun #3 in our overall mixer since it

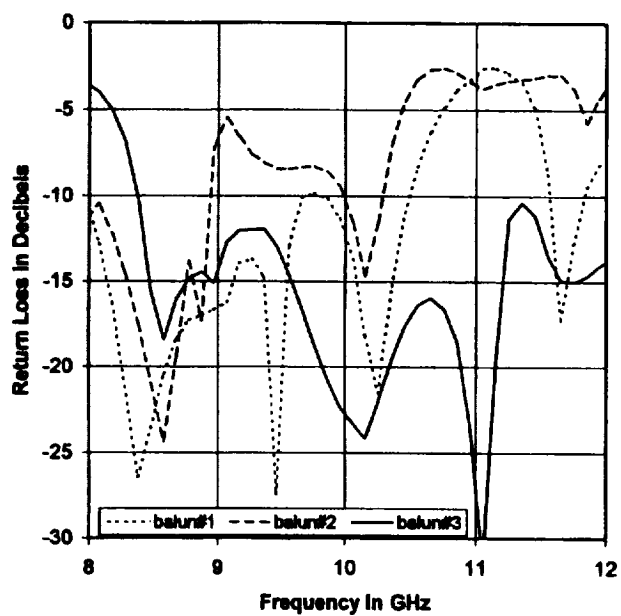


Figure 3. Measured return loss of back to back baluns.

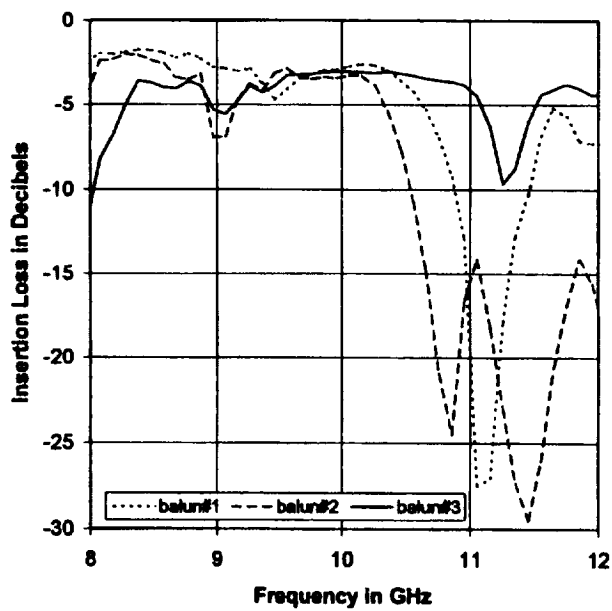


Figure 4. Measured insertion loss of back to back baluns.

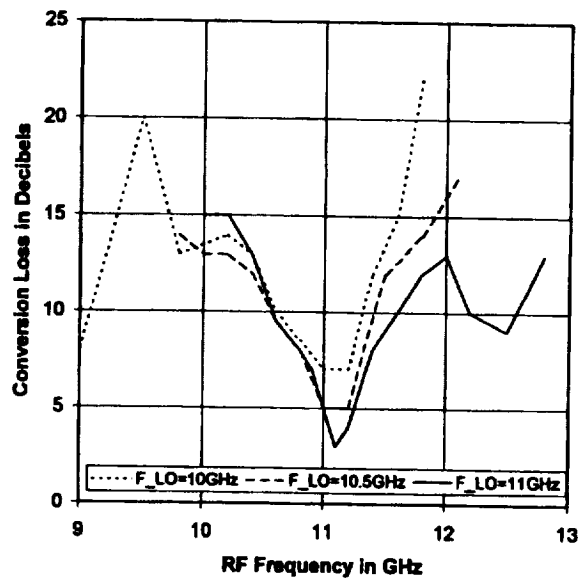


Figure 5. Mixer's isotropic conversion loss for three LO frequencies.

provides very good return loss and insertion loss over a wide bandwidth centered at our design frequency of 10 GHz.

To make sure that the converter transforms the even-mode to an odd-mode we fabricated and tested the converter by itself using balun #3. Since the coaxial adapters attached to the input and output coplanar waveguides short out the odd-mode (the slotline mode) we expect to see very little transmission and very high reflection if the converter is working properly. Measurements confirmed our expectation where the measured return loss was very high and the insertion loss was less than  $-32$  dB for the entire X-band.

The overall mixer was fabricated using a precision milling machine. The diodes used were low-barrier zero-bias Schottky diodes. The slot antenna was designed to operate at the second resonance [9] with a length of 15 mm and slot width of 0.8 mm. Twin slot antennas attached to a dielectric lens [7, 10] can be used instead to make the antenna unidirectional and to improve directivity. The isotropic conversion loss of the mixer was measured for several RF frequencies as shown in figure 5. The LO frequency was chosen at 10, 10.5, and 11 GHz. A minimum conversion loss of 3 dB at 11.3 GHz RF frequency was obtained for 11 GHz LO frequency. The LO to IF isolation was better than  $-45$  dB's for all frequencies measured. The overall performance

can be enhanced further with more accurate fabrication techniques, better diodes, and by using twin-slot antennas attached to a dielectric lens.

### 3. CONCLUSION

We have successfully demonstrated a new, simple, and efficient uniplanar mixer suitable for microwave and millimeter wave frequencies. Balanced mixing was obtained utilizing even and odd modes on coplanar waveguides with good conversion loss and isolation. The mixer performance can be enhanced by monolithic fabrication. The design can be easily extended to use twin-slot antennas and a dielectric lens at millimeter wave frequencies.

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**Mohammad A. Saed** received the B.Sc. degree in Electrical Engineering from Middle East Technical University, Ankara, Turkey in 1983. He received the M.S. and Ph.D. degrees in Electrical Engineering from Virginia Tech, Blacksburg, in 1984 and 1987, respectively. He worked in the same school as a post doctoral research associate until August 1989. He then joined the Department of Electrical Engineering, State University of New York New Paltz, where he is currently an associate professor. He spent the summer of 1996 at The Jet Propulsion Laboratory, Pasadena, as a Summer Faculty Fellow funded by the NASA/University Joint Venture Program. His current research areas of interest include microwave and millimeter wave circuits, planar and integrated antennas and arrays, and microwave photonics for wireless communications.

**Jonathan D. Fredrick** was born in Bayside, New York in 1975. He received the B.S. degree in electrical engineering from the State University of New York, New Paltz in 1997. He is currently working towards the M.S. degree at the University of California, Los Angeles. During the 1996 and 1997 academic years he received two research stipends under the NASA/University Joint Venture Program. His current research interests include the design of active antennas and systems for vehicular and personal communication systems. Mr. Fredrick was recently awarded the 1999 IEEE MTT-S Graduate Fellowship.